CONCERNING THE USE OF A 920 DOUBLE PHOTO-CELL IN A CURRENT AMPLIFIER AND STABILIZER

By B. M. BANERJEE* and S. K. SEN

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ABSTRACT. The characteristics of a gas-filled double photo-cell G. E. 920 as a translator element in a current stabilizer circuit has been studied. The characteristics are explained in the light of ionization in the residual gas in the common envelope. The characteristics differ from, and are inferior to that of two separate photo-cells or a vacuum double photo-cell. Gas-filling results in a deterioration rather than an improvement, of the characteristics of the tube as a translator element of a current amplifier or stabilizer.

INTRODUCTION

The 920 photo-cell is commonly used in a translator† circuit of the type given below. In a circuit of this type, it is frequently found that so long as B=B′, the system operates with the light shining mainly or wholly on one

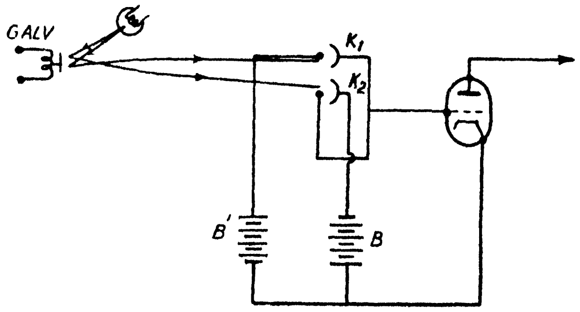


FIG. 1.

A commonly used galvanometer photo-tube translator circuit.

photo-cathode. In extreme cases the system refuses to function altogether. It is also found that the system may be made to function properly by making B′ somewhat smaller than B.

* Fellow of the Indian Physical Society.

† A current amplifier consists of the following parts :—

(*a*) A translator which converts current variations into voltage variations sufficiently large to actuate a vacuum tube d.c. amplifier.

(*b*) A vacuum tube d c amplifier of a maximum current output equal to that specified for the current amplifier.

(*c*) A network for feeding back a portion of the amplified output current in opposite phase to ensure linearity and to stabilize the amplification to the desired level.

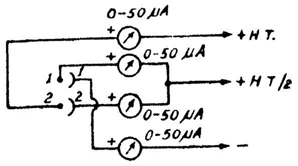
The translator usually consists of a galvanometer whose light spot shines on a double photo-cell in a circuit of the type shown in the figure. This arrangemen twas first utilised by Gilbert (1936).

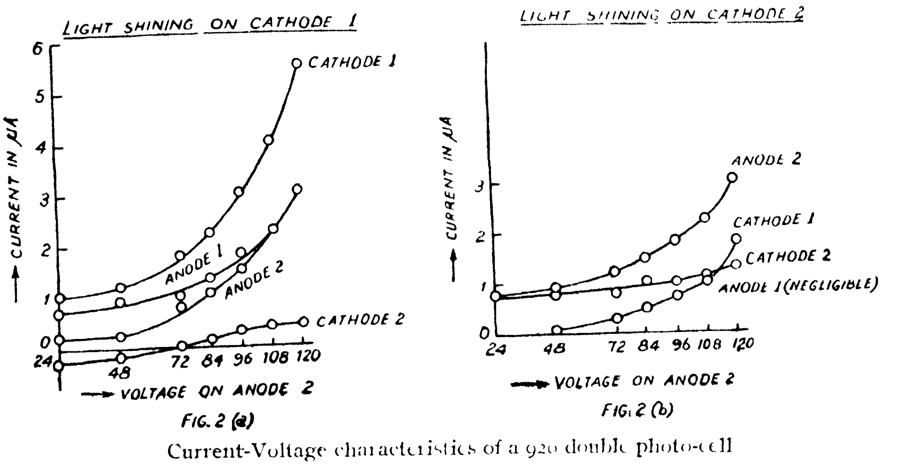
EXPERIMENTS AND RESULTS

This observation points to the existence of an assymmetry in the sensitivities of the photo-cathodes, resulting out of its peculiar connection in this particular circuit.

The characteristics of the photo-cell in this circuit has, therefore, been studied thoroughly—the result of which is given in the curves of Figs. 2 and 3.

Fig. 2 represents the current voltage characteristics of all the electrodes in the photo-cell—Fig. 2(*a*) with the light shining wholly on cathode 1—the cathode at the lowest potential and Fig. 2(*b*) with the light shining wholly on cathode 2—the cathode at the intermediate potential. Experimental arrangement is indicated in the figure.





Current-Voltage characteristics of a 920 double photo-cell

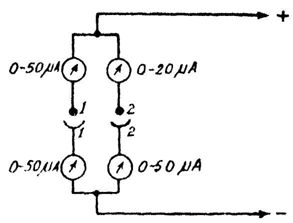
The following observations require particular mention :

1. The electrodes of both the photo-cells pass current even when light shines wholly on one photo-cathode.

2. The magnitudes of the currents passed by the different electrodes are greater when light shines on the photo-cathode at the lower potential.

3. The difference in the magnitude of the currents with light shining wholly on one or the other photo-cathode increases with the total voltage applied on the photo-cell.

Fig. 3 gives what may be called the *translation* characteristic—output voltage *vs.* light spot position of the photo-cell. As the position of the light spot depends upon the galvanometer current—galvanometer current is plotted as the abscissa of the points in the curves. With no current in the galvanometer, illumination on both the photo-cathodes are the same.



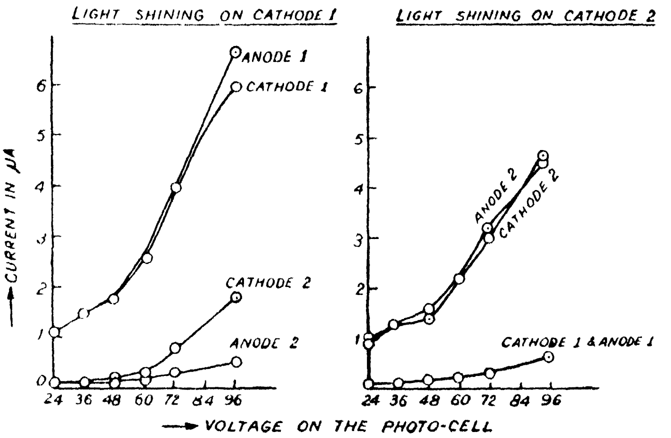


FIG. 2 (C)

The measurement of the "Output Voltage" of the photo-cell is a difficult problem. This voltage lies in the range of 20-70 volts. The photo-cell circuit is a high resistance circuit—inasmuch as only a few micro-amperes are passed

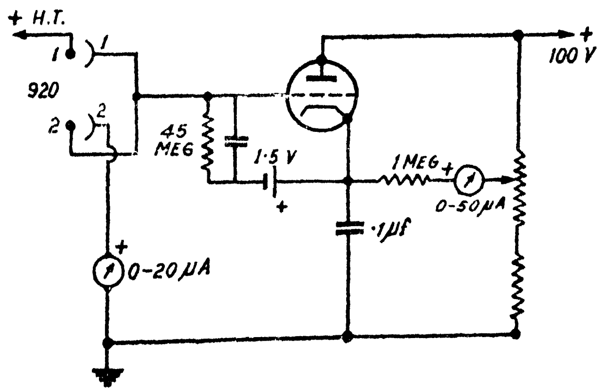


FIG. 3.

Experimental arrangement for obtaining the translation characteristic of a 920 double photo-cell. The voltmeter tube is a 6C6 connected as atriode. The filament voltage is reduced to 4.8 volts in order that the tube may have a high input resistance.

by the photo-cell elements at considerable voltages. A vacuum tube voltmeter of high input resistance, which can measure positive voltages in the range of 20-70 volts, is therefore necessary The solution is found in the circuit of Fig. 3. This valve voltmeter has an input resistance approximately equal to μ Rg which is about 800 megohms. The grid leak of 45 megohms together with a bias of 1.5 volts is necessary as otherwise the pointer of the indicating 50 μA-meter moves out of scale when the light spot moves away from both the photo-cathodes. A condenser of .002 μf capacity bypasses the ripples picked up by the grid of the valve-voltmeter.

The curves in Fig. 3 point towards the following observations.—

1. The centre voltage of the curves is not necessarily equal to half the photo-cell supply voltage—being usually considerably greater than half the supply voltage.

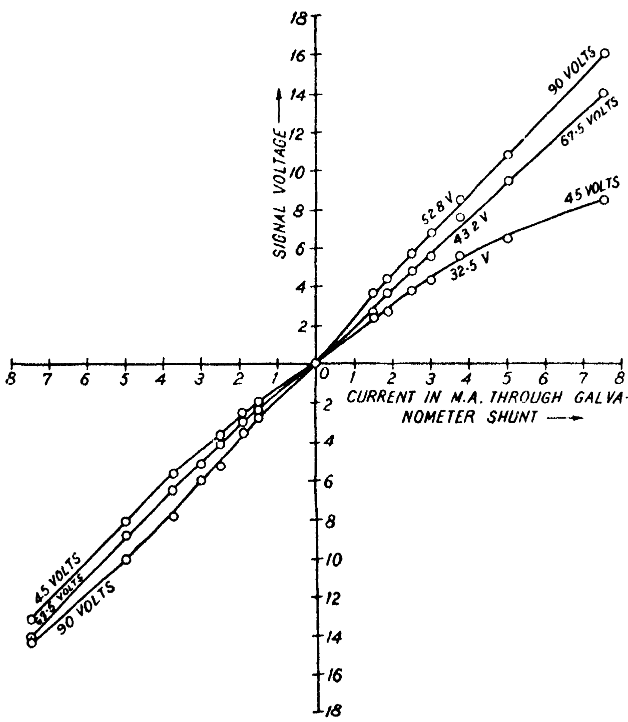


FIG. 3 (a)

Translation characteristics of a 920 double photo cell translator The voltage applied across the 920 photo-cell as well as the centre voltage is written down at the side of each characteristic. The ordinates give the signal voltage, output voltage being obtained by adding this amount to the corresponding centre voltage The extreme points—with 7.5 m.A. through the galvanometer shunt—represent points when the light shines wholly on one cathode; the centre point with light equally on both cathodes. The spot of light is of diamond shape being obtained by reflection from the mirror of same shape of a Rubicon Portable spotlight galvanometer. The lamp is a 6.3 volt, 1 Ampere incandescent lamp—running at 7 volts. Light is collected through a small double convex condenser lens.

2. The range* of output voltage is a small fraction of the supply voltage. With two separate photo-cells or with a vacuum double photo-cell it would almost equal the supply voltage in magnitude†. With the reduction of the supply voltage this fraction improves.

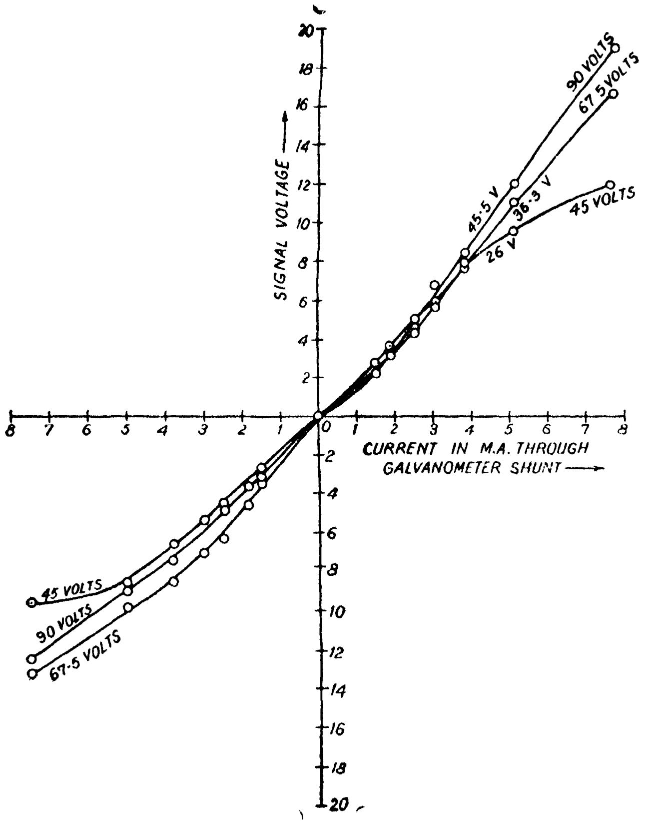


FIG. 3 (b)

The 67 5 volt characteristic of Fig 3(b) crosses the 90 volt characteristic. This is somewhat abnormal. It is perhaps the result of a reduction in the intensity of light when the 90 volt curve was taken.

3. The slopes of the characteristics diminish only slightly with decrease of the supply voltage. The absolute magnitude of the range of output voltages does not get much reduced even when the supply voltage is diminished considerably

The vacuum tube d.c. amplifier in the amplifier-stabilizer system operates over a limited range of input voltages. At the extremes of this range, the

*The output voltage is a maximum when light shines wholly on cathode 1 and a minimum when light shines wholly on cathode 2. With light shining on both cathodes, the output voltage may have any value between these two extremes. The range of output voltage is the difference between these two voltages.

†It is obvious that with two separate photo-cells or a vacuum double photo-cell the maximum output voltage will approach the supply voltage while the minimum will approach zero. As a result the range of output voltage almost equals the supply voltage

output current is either zero or the saturated maximum value. The whole system may function only when the d.c. amplifier functions. So in order that the system may operate, the output voltage of the photo-cell must fall in this range. If the centre voltage of the photo-cell translator, coincides with the working range of the input voltage of the d.c. amplifier, the system operates in a balanced condition, *i.e.*, light shining equally on both photo-cathodes. Otherwise there is unequal illumination on the photo-cathodes. In this case variations in the intensity of the illuminating lamp will cause changes in the output voltage of the photo cell and so changes in the output current of the amplifier stabilizer. This is undesirable It defeats the advantages of using a double photo cell translator. So arrangements must be provided in order that the centre voltage of the translator may be made to coincide with the working range of the input voltage of the d.c. amplifier. This may be accomplished by one or two potentiometers controlling the voltage on the photo-cells. Such adjustments will be found provided in some of the current stabilizers described in literature.* The authors of these articles however did not mention that such a provision of adjustment is inherently necessary to overcome the peculiarity of the 920 double photo cell in this particular circuit. All of them appear to have overlooked that the centre voltage of a 920 translator is usually greater than half the supply voltage.

EXPLANATION OF THE OBSERVATIONS

The 920 photo-cell is a gas filled one. This gas therefore has to explain the observed peculiarities A vacuum photo-cell cannot presumably show such characteristics.

Gas multiplication occurs due to the generation of ions by collision. This process takes place in the regions where there is a high field gradient, *i.e.*, near about the wire anodes. Positive ions move out from these regions to the two cathodes and constitute the major fraction of the cathode currents.

Curve 2(*a*)—Light shining wholly on cathode 1 (Fig. 2).

Electrons emitted from the photo-cathode 1 are captured by anode 1, anode 2, and also cathode 2, as all these are at a higher potential compared to the cathode 1. This explains the negative current registered by cathode 2, at low voltages where primary electrons constitute a good fraction of the currents. At higher voltages the collisional ions increase in number and the currents increase. At a particular value of the supply voltage, the positive ion current intercepted by cathode 2 equals the electron current received from cathode 1, and hence the cathode 2 current falls to zero. At still greater voltages, a greater number of positive ions are received by cathode 2 and so the cathode 2 current becomes positive.

As the collisional multiplication follows Townsend's (1915) exponential law, the currents of all the electrodes increase rapidly with voltage. Anode 2 rec[illegible]s

* Chang. (1946); Lawson and Tyler (1939); T.R.E Newsletter No. 3.

electrons from the ionized regions near about anode 1. As the ionization process is involved twice in the production of the anode 2 current, anode 2 current increases more rapidly than anode 1 current. Cathode 1 current is the largest of all the currents as cathode 1 receives most of the positive ions both from anode 1 and 2.

Curve 2 (*b*)—Light shining on cathode 2—the cathode at the intermediate potential.

Photo-electrons emitted by cathode 2 are captured only by anode 2. Positive ions generated at anode 2 move out and are captured by both cathodes. As the positive ions form a sheath around anode 2, the potential fall around anode 2 rapidly equals the potential difference existing between anode 2 and cathode 2, tending to approach the potential of cathode 1—the cathode at the lowest potential. Cathode 1 draws positive ions from this sheath of ions. As the supply voltage is increased more collisional positive ions are generated but the greater fraction is received by cathode 1 and so cathode 1 current increases rapidly. Cathode 2 current remains almost constant. Anode 1 current remains negligible as it is an electrode of small surface area, at an intermediate potential, situated out of the direct path of the positive ions.

When light shines on cathode 1-the cathode at the lowest potential, collisional multiplication takes place in the regions near about both the anodes. Whereas when light shines on cathode 2—the cathode at the intermediate potential collisional multiplication occurs near about one anode—(anode 2)—only. As a result the electrode currents in the first case are generally greater in magnitude than in the second case.

Curves in Fig. 2(c)—Confirm the above explanations. These are obtained with the electrodes of both the photo-cells at similar potentials. It is observed that a small current is passed by both the electrodes of the dark photo-cell This proves that some of the ions from the illuminated photo-cell stray into the region of the dark photo-cell.

It is not possible to derive the curves in Fig. 3 from those in Fig. 2. For that it is necessary to obtain current voltage characteristics with illumination on both photo-cathodes, as well as to obtain characteristics with differing voltages on anode 1 and cathode 2. However, curves in Fig. 2 are sufficient to indicate that the output voltage with equal illumination on both photo cathodes will not be half the supply voltage and also that the range of output voltage will not be as great as that of a translator using two separate photo-cells.

CONCLUSION

The operation of a gas filled double photo-cell like 920, as a translator element converting current variations into voltage variations, in current amplifier-stabilizer circuits is not so simple as is usually thought to be. As a result (*a*) the output signal voltage of the translator with equal illumination on both photo-cathodes is not equal to half the supply voltage and (*b*) the range of output signal is a small fraction of the supply voltage. Now the vacuum tube amplifier which follows such a translator element in a current stabilizer circuit operates over a limited range of input voltages. For perfect functioning of the whole system, it is necessary that the working range of the input voltage of the d.c. amplifier falls at the centre of the translator output voltage. This can be achieved by suitable potentiometers balancing the photo-cell voltages. As a matter of fact such an arrangement is absolutely necessary.

A translator using two similar and separate photo-cells or a vacuum double photo-cell possesses a much greater range of output voltage. As a result it is more sensitive and less critical of adjustments. A vacuum double photo-cell translator would have of course a greater, but more constant internal resistance. This, however, is not a serious shortcoming inasmuch as it is quite possible to design the following d c. amplifier such that it possesses a sufficiently high input resistance.

In short, a gas filled double photo-cell translator requires careful adjustments and is less sensitive compared to two separate photo-cells or a vacuum double photo cell. A better translator tube would have resulted if the filling gas were not introduced.

PALIT LABORATORY OF PHYSICS,
UNIVERSITY COLLEGE OF SCIENCE, CALCUTTA

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